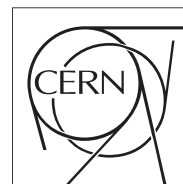


The Compact Muon Solenoid Experiment

# Conference Report

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## Charmonium production measured in PbPb and pp collisions by CMS

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### Abstract

The Compact Muon Solenoid (CMS) is fully equipped to measure hard probes in the di-muon decay channel in the high multiplicity environment of nucleus-nucleus collisions. Such probes are especially relevant for studying the quark-gluon plasma since they are produced at early times and propagate through the medium, mapping its evolution. CMS is able to distinguish non-prompt from prompt  $J/\psi$  in  $pp$  and PbPb collisions. We report here the nuclear modification factor of prompt  $J/\psi$  in PbPb as a function of transverse momentum, rapidity, and the number of nucleons participating in the collision.

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The goal of the SPS, RHIC, and LHC heavy-ion programmes is to probe the existence and study the properties of the quark-gluon plasma (QGP), a state of deconfined quarks and gluons. In such a state it was predicted [1] that quarkonium production is suppressed by Debye screening of the heavy quark binding potential. Therefore, the observation of such suppression is considered one of the most promising signatures of the creation of the QGP. At LHC energies and luminosities, the contribution of non-prompt  $J/\psi$  from B-hadron decays to the inclusive  $J/\psi$  cross-section is non-negligible and needs to be considered. CMS has been able to separate prompt from non-prompt  $J/\psi$  not only in  $pp$  collisions at  $\sqrt{s} = 7$  TeV [2], but also in the much more challenging environment of PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV [3]. In this proceedings, the CMS measurement of prompt  $J/\psi$  production in PbPb collisions are reported. The results are presented as nuclear modifications factors  $R_{AA}$  based on a comparison to the yield measured in a  $pp$  reference run at the same  $\sqrt{s_{NN}}$ .

The central feature of CMS is a superconducting solenoid, of 6 m internal diameter, providing a field of 3.8 T. Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL). Muons are measured in gas-ionization detectors embedded in the steel return yoke. In addition to the barrel and endcap detectors, CMS has extensive forward calorimetry. The muons are measured in the pseudorapidity window  $|\eta| < 2.4$ , with detection planes made of three technologies: Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers. Matching the muons to the tracks measured in the silicon tracker results in a transverse momentum resolution better than 1.5% for  $p_T$  smaller than 100 GeV/c. A much more detailed description of CMS can be found elsewhere [4].

The  $J/\psi$  analysis in PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV is based on a double-muon triggered data set recorded during the LHC heavy-ion run in 2010 and corresponds to a total integrated luminosity of  $\mathcal{L}_{\text{int}} = 7.28 \mu\text{b}^{-1}$ . The analysis follows closely the one performed in  $pp$  collisions at  $\sqrt{s} = 7$  TeV whose results are reported in [2]. In the offline analysis, muon candidates are reconstructed as tracks in the muon detectors. These tracks are then matched to tracks reconstructed in the silicon tracker, based on algorithms optimized for the high multiplicity environment of heavy-ion collisions [5]. Muons are further identified by cuts on the quality of the tracks reconstructed in the silicon tracker as well as the ones in the muon chambers. Opposite-sign muon pairs with an invariant mass between  $2.6 \text{ GeV}/c^2$  and  $3.5 \text{ GeV}/c^2$  and a good common vertex probability are considered for the  $J/\psi$  analysis. Their invariant mass distribution is shown in the left panel of figure 1 for  $\mu^+\mu^-$  pairs with  $6.5 < p_T < 30 \text{ GeV}/c$  integrated over the rapidity range  $|y| < 2.4$  and the centrality range 0–100%. The  $J/\psi$  peak is well reconstructed with a mass resolution of  $34 \text{ MeV}/c^2$ . The data are fitted with a Crystal Ball function plus an exponential for the background. To distinguish prompt from non-prompt  $J/\psi$ , the pseudo-proper decay length  $\ell_{J/\psi} = L_{xy} \cdot m_{J/\psi} / p_T$  is computed for each  $J/\psi$  candidate.  $L_{xy}$  is the most probable transverse decay length in the laboratory frame defined as:

$$L_{xy} = \frac{\hat{u}^T \sigma^{-1} \vec{x}}{\hat{u}^T \sigma^{-1} \hat{u}} \quad (1)$$

where  $\vec{x}$  is the vector joining the dimuon vertex and the collision vertex of the event,  $\hat{u}$  is the unit vector of the  $J/\psi$   $p_T$ , and  $\sigma$  is the sum of the primary and secondary vertex covariance matrices [2]. The fraction of non-prompt  $J/\psi$  is determined by an unbinned maximum likelihood fit in bins of  $p_T$ , rapidity, and centrality [3, 6]. The invariant mass and the pseudo-proper decay length distributions are fitted simultaneously. The projection along  $\ell_{J/\psi}$  is shown in the right panel of figure 1 in which the data are overlaid with the different contributions to the fit: prompt signal, non-prompt signal and background. In March 2011, a reference sample of  $pp$  collisions at  $\sqrt{s} = 2.76$  TeV has been collected. It corresponds to an integrated luminosity of

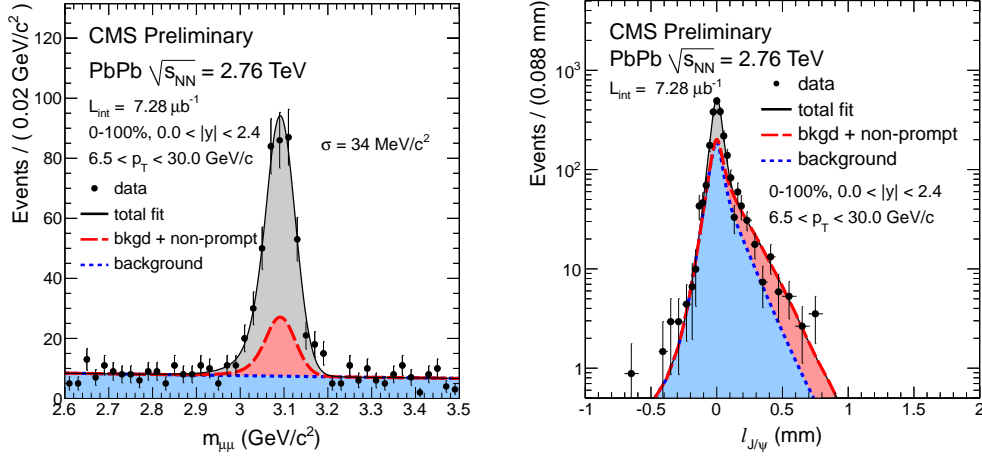


Figure 1: Invariant mass spectrum (left) and pseudo-proper decay length (right) of  $\mu^+\mu^-$  pairs with  $6.5 < p_T < 30$  GeV/c and  $|y| < 2.4$  integrated over the centrality range 0–100%. The data (black circles) are overlaid with the projections of the 2-dimensional fit. The different contributions are background (dotted blue line), non-prompt J/ $\psi$  (dashed red line), and the sum of background, non-prompt and prompt J/ $\psi$  (solid black line).

$\mathcal{L}_{pp} = 225 \text{ nb}^{-1}$ . The data are reconstructed with the same heavy-ion optimized reconstruction algorithms and the analysis is performed identically to the PbPb analysis.

Based on the J/ $\psi$  raw yields  $N_{\text{PbPb}}(\text{J}/\psi)$  and  $N_{pp}(\text{J}/\psi)$  measured in PbPb and  $pp$  collisions, respectively, the nuclear modification factor

$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{N_{\text{PbPb}}(\text{J}/\psi)}{N_{pp}(\text{J}/\psi)} \frac{\varepsilon_{pp}}{\varepsilon_{\text{PbPb}}} \quad (2)$$

has been calculated. The only correction applied is a multiplicity dependent difference of the trigger and reconstruction efficiencies in PbPb and  $pp$  collisions ( $\frac{\varepsilon_{pp}}{\varepsilon_{\text{PbPb}}} = 1.17$  for the most central bin).  $T_{AA}$  is the nuclear overlap function and  $N_{MB}$  the number of sampled minimum bias PbPb collisions. The trigger and reconstruction efficiencies are calculated using Monte Carlo simulations where a PYTHIA signal event is embedded into a background event simulated with HYDJET [7]. These events are processed through the full CMS trigger emulation and event reconstruction chain. The results are cross checked with real data using a *tag and probe* technique [3].

The resulting  $R_{AA}$  of prompt J/ $\psi$  with  $6.5 < p_T < 30$  GeV/c and  $|y| < 2.4$  is shown in figure 2 as function of the number of participating nucleons ( $N_{\text{part}}$ ). A centrality dependent suppression of prompt J/ $\psi$  production is observed. In the 10% most central events, the suppression reaches a factor of 5 with respect to the  $pp$  reference. The suppression decreases towards peripheral events to a factor 1.6 in the 50–100% centrality bin. The results are compared to measurements in AuAu collisions at  $\sqrt{s_{NN}} = 200$  GeV by PHENIX [8] and STAR [9]. The PHENIX results, measured in two rapidity ranges ( $|y| < 0.35$  and  $1.2 < |y| < 2.2$ ) at much smaller  $p_T$ , show a surprisingly similar suppression pattern. The STAR result of the J/ $\psi$   $R_{AA}$  for  $p_T > 5$  GeV/c, however, shows less suppression than measured by CMS. The  $p_T$  and rapidity dependence of the  $R_{AA}$  are shown in figure 3. No strong  $p_T$  dependence is observed in the measured range. There is some indication for a decrease of the suppression at forward rapidity. As for the centrality dependence, the data are compared to results from PHENIX and STAR. The rapidity dependence of the suppression measured by PHENIX at low  $p_T$  seems to indicate the opposite trend with respect to the CMS measurement at high  $p_T$ . The STAR data show less suppression

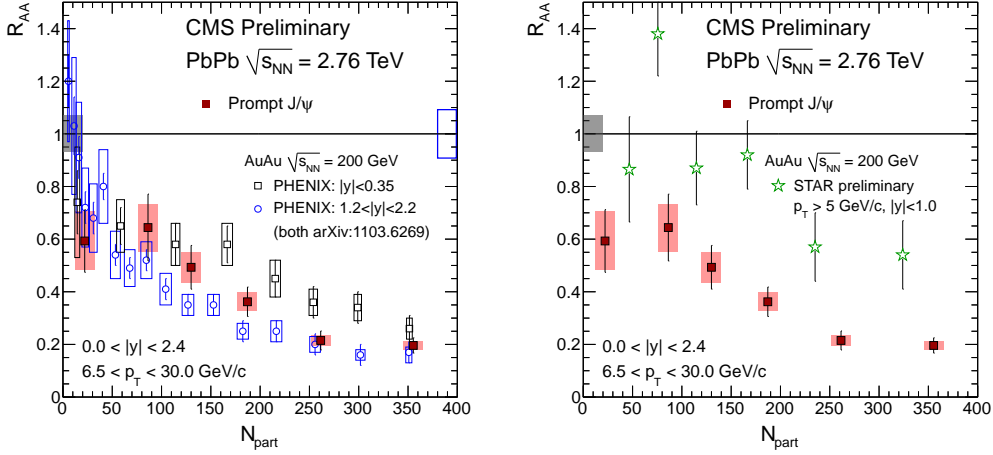


Figure 2:  $R_{AA}$  of prompt  $J/\psi$  (red squares) as function of  $N_{part}$ . The left panel shows the comparison to PHENIX data at mid- (open black squares) and at forward rapidity (open blue circles). The right panel compares to STAR data (green stars).

of high  $p_T$   $J/\psi$  at RHIC energies than at the LHC.

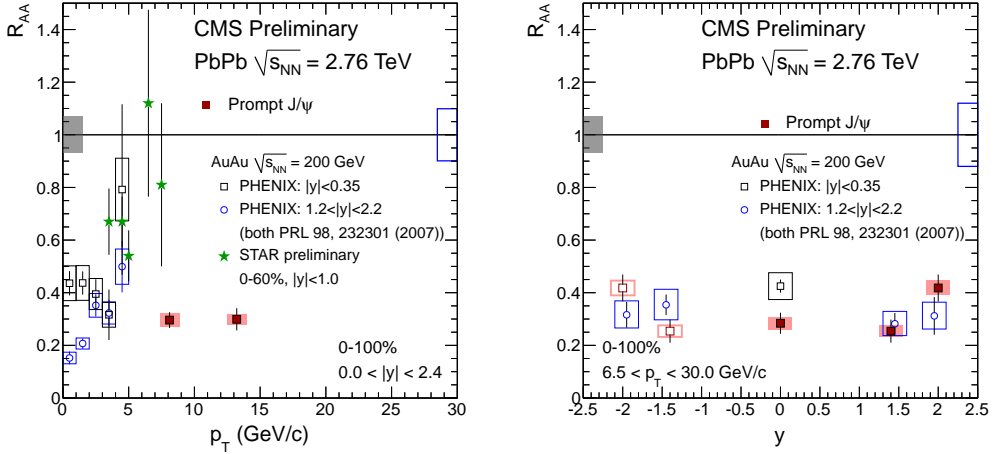


Figure 3:  $R_{AA}$  of prompt  $J/\psi$  (red squares) as function of  $p_T$  (left) and rapidity (right). The data are compared to PHENIX and STAR results.

CMS has separated the prompt  $J/\psi$  from the non-prompt contribution due to B-hadron decays. The nuclear modification factor of prompt  $J/\psi$  has been measured as function of centrality,  $p_T$ , and rapidity in PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV. A suppression of prompt  $J/\psi$  has been observed, which increases with centrality up to a factor of 5. CMS has also measured the  $R_{AA}$  of non-prompt  $J/\psi$  which gives access to the in-medium energy loss of b-quarks [3, 6].

## References

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